

## CHAPTER 31

### SECONDARY CELLS

The dry cell has the disadvantage that it can only be discharged once after which it is discarded. From Chapter 30 it can be seen that this occurs because the negative electrode passes into solution due to chemical reactions. Another disadvantage is that the negative electrode also deteriorates through 'local action', a process which occurs due to impurities on the surface of the electrode forming their own cells with the electrolyte. Finally the cell may 'dry out', a term used when the cell loses the moisture necessary to allow for the movement of the positive and negative ions. While the dry cell is a useful and a cheap source of electricity the foregoing limitations severely restrict its applications.

#### 31.1 SECONDARY CELLS

A secondary cell is one which can be discharged and recharged over a period of time. Like all cells, in a charged condition it must consist of two dissimilar materials in the presence of an electrolyte. During the discharging cycle chemical reactions at the electrodes change the electrode material compositions so that they are almost identical, under which condition the t.p.d. of the cell is reduced to a very low value. During a recharging cycle the composition of the electrodes is restored to their original conditions, allowing the cell to again be used as a source of e.m.f.

The two main types of secondary cells are:-

- (a) the lead acid cell
- (b) the alkaline cell

#### 31.2 THE LEAD ACID CELL

The electrodes in a lead acid cell are made in the form of plates. The function of the plates is to provide the active material which gives rise to the electric current via chemical reaction. One of the determinants of battery capacity is the quantity of lead available for reaction with the electrolyte and this is an important reason why **pasted plates** are used in most lead-acid storage batteries. Pasted plates consist of a grid which is a lead casting, and **paste** which is the active material. A partially pasted plate is shown on a typical lead grid in figure 31.1.

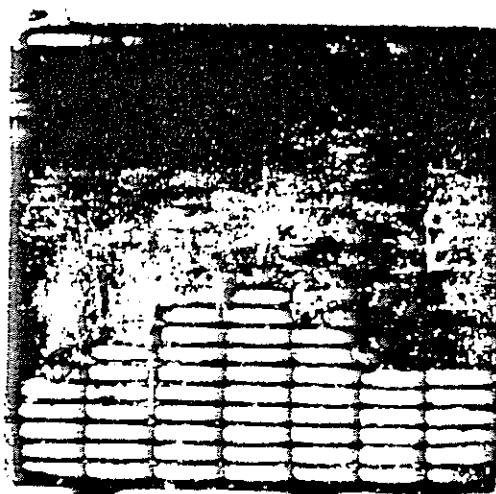


Figure 31.1

The grid provides the supporting framework for the paste, and also conducts the electric current through the paste. It is made mainly of antimonial lead alloy, the antimony (about 6%) being used to sharpen and strengthen the casting.

The paste is prepared from a mixture of lead oxide ( $\text{PbO}$ ) and dilute sulphuric acid, with small quantities of negative plate expanders and other ingredients.

Both positive and negative plates are manufactured in the same way, but the plates undergo chemical reactions before the cell is constructed. The negative plate becomes 'spongy' lead and the positive plate becomes lead dioxide. The new plates are easily recognised by the colour. The lead oxide plate is a reddish colour while the spongy lead is grey. (Figure 31.2).

Figure 31.2



When the cell is formed, the plates containing the different compounds of lead are placed in a container with diluted sulphuric acid as the electrolyte. During the discharging of the cell, lead dioxide is reduced to lead sulphate at the positive plate, and at the negative plate lead is oxidised to lead sulphate. Note that lead sulphate is formed on both plates while the battery is discharged. In the recharging process, the lead sulphate on the electrodes reverts to lead dioxide and 'spongy' lead. The open circuit t.p.d. of a lead acid cell is approximately 2 volts

### 31.3 ALKALINE CELLS

The alkaline cell most in use is the nickel cadmium cell. Nickel iron cells were very popular in the past but the lower cost, higher efficiency and reliability of the nickel cadmium cell have caused them to virtually supercede the nickel iron cell.

Two different types of vented or open Nickel Cadmium Cells are available.

- (a) The sintered nickel cadmium where the electrode matrix is sintered nickel powder on a gauze or perforated metal sheet insulated by a woven or non-woven plastic fabric. They are not widely used because of lower performance and higher price than the pocket plate nickel cadmium cell.
- (b) Pocket plate nickel cadmium cells are precision made and are designed for exceptionally long life - 25 years plus.

The heart of every cell is a series of steel pockets which are made from finely perforated steel strips filled with active materials. (Figure 31.3).

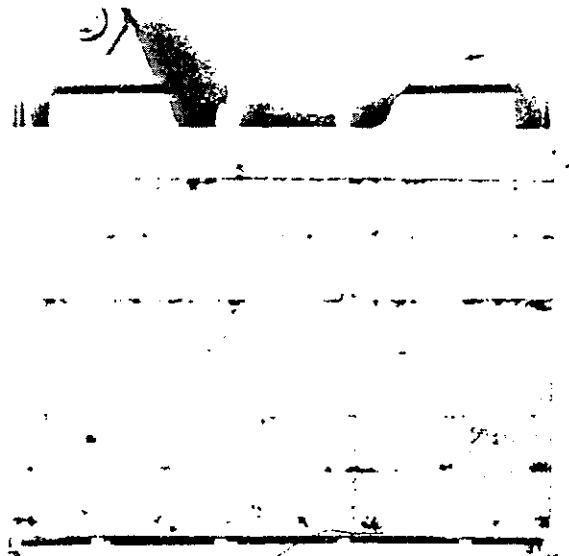


Figure 31.3

The active materials are cadmium in the negative and nickel in the positive plate. Plates of the same polarity are either welded or bolted together with plastic insulators between, and then sealed in a plastic or steel container with potassium hydroxide solution as the electrolyte.

The use of steel for the plate 'grid' and other components give the nickel cadmium cell great physical strength, and although oxygen is formed during charging, the steel components in alkali solutions are not affected by it. This is particularly so when the steel strip material is nickel plated.

In NiCd cells, the alkali electrolyte does not enter the chemical reactions during charge and discharge except to carry the ions during the process, whereas in the lead cells, the sulphuric acid reacts with the lead of the negative plate which accounts for the fall in electrolyte density during discharge.

The NiCd cell then is extremely resistant to both overcharge, as there is no corrosion of the cell components, and, undercharging as no corresponding chemical reaction to the sulphation of a lead battery can take place.

Hence the chemical, physical and electrical properties of pocket plate nickel cadmium provide the longest life reliability.

(c) Sealed nickel cadmium cells

In the sealed nickel cadmium cell both the anode material (cadmium) and the cathode material (nickel oxide) are contained in porous plates. (Figure 31.4).

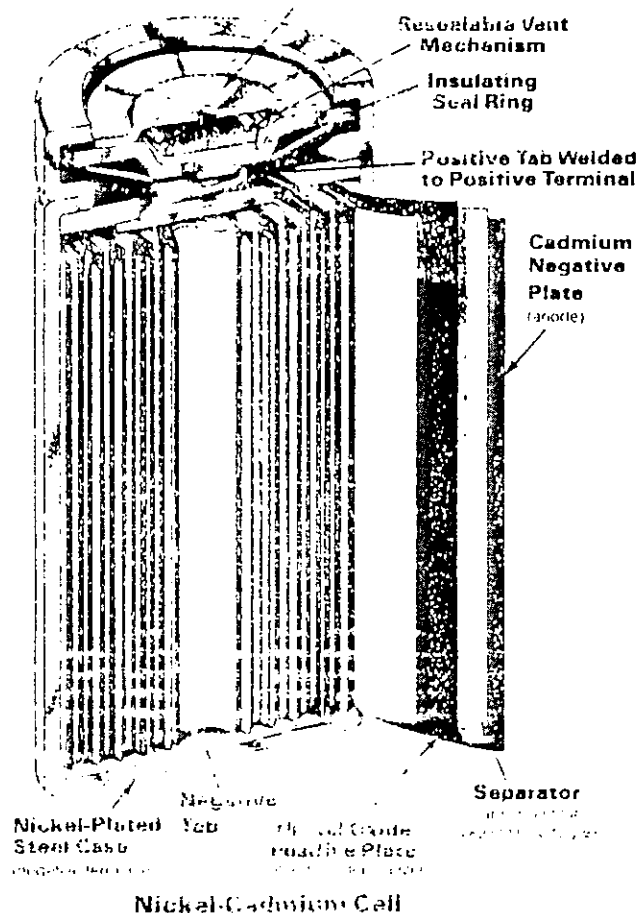


Figure 31.4

The plates not only hold the cadmium and nickel in place; they are also conductive, increasing the efficiency of the system. Because of this design the anode structure is not seriously distorted as the cadmium is oxidized; nor is the cathode, as the nickel is reduced. Consequently the system can be recharged, driving the oxygen back to the cathode and restoring the cell's capacity once again.

To date, the major consumer applications for these cells have been in the calculator industry and for small portable power tools.

Like every 'first', nickel cadmium rechargeables naturally have their disadvantages. The cells, along with the recharging unit, are expensive. They do not retain a charge well on the shelf and they can only store a relatively limited amount of energy to begin with.

### 31.4 CURRENT AND t.p.d. OF SECONDARY CELLS

The terminal potential difference of a cell depends on the types of material used as the electrodes. This applies to primary and secondary cells alike. If the t.p.d. required is more than that produced by one cell, cells are connected in series until the required voltage is reached. With dry cells, four 1.5 V cells are connected in series to form a 6 volt battery, while with lead acid cells three 2 V cells are connected in series to produce the same result. The connections are usually made internally during the construction of the battery and only two battery terminals appear.

The current that can be delivered by a cell depends largely upon the amount of electrode material that can participate in the chemical reactions. The small cells, both primary and secondary are limited in their output due to the size necessary to make them portable. The forming of secondary cell electrodes into the plate shape allows large quantities of electrode material to be pasted to the plates. This results in a higher power (t.p.d.  $\times$  I) output of the cell. The output of the cell, or current able to be delivered continuously by the cell, can be further increased by paralleling identical plates and using them as one of the cell electrodes. (Figure 31.5).

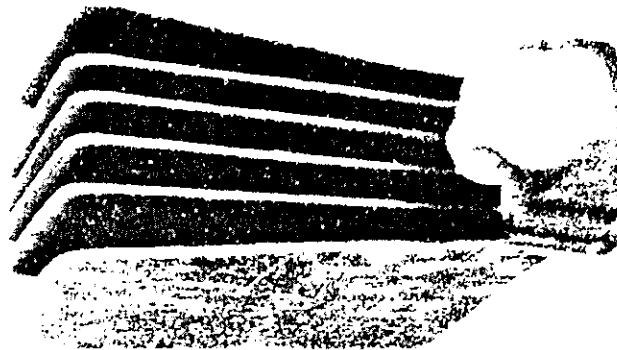


Figure 31.5

The paralleling of plates effectively increases the plate area. A common method of describing a battery is by its t.p.d. and the number of plates in each cell (for example 12 volt 9 plate, 12 volt 13 plate). The higher the number of plates the greater the power output of the cell when in a new, fully charged condition. In a lead acid cell there is one more negative plate than positive plates, (figure 31.6), the plates being separated by insulators.

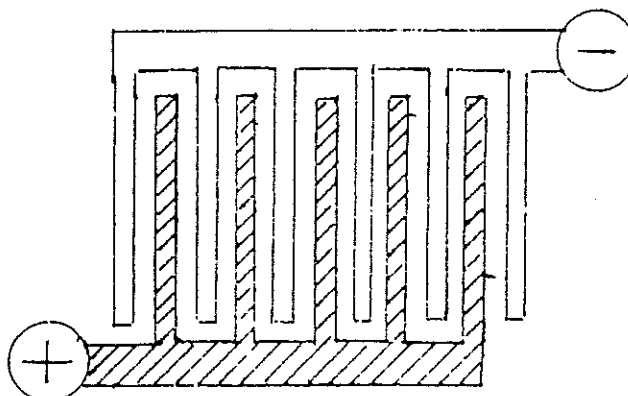


Figure 31.6

As the most volatile chemical reactions occur at the positive plate, enclosing the positive plates with negative plates both increases the efficiency of the cell and prevents the distortion of the positive plate during the charging and discharging cycle. In an alkaline cell the electrodes are so solidly constructed that distortion does not occur and depending on design, there may be more negative or more positive plates in the cell.

### 31.5 MAINTENANCE OF SECONDARY CELLS

Small secondary cells are sealed and are not maintained. They undergo a number of charge and discharge cycles over a period of time and are discarded when their output, in a charged condition, is insufficient to perform the required operation. Larger output cells or batteries, such as those used for traction or emergency lighting require periodic attention during their lifespan. The main area requiring maintenance is the electrolyte, which changes its concentration or more correctly its specific gravity. It also loses water due to evaporation during the charging and discharging cycles. The specific gravity of an electrolyte is checked or measured by using a hydrometer. (Figure 31.7).



Figure 31.7

A hydrometer is like a oversized syringe. The outer glass housing contains a glass float with a calibrated stem. The rubber spout on one end of the hydrometer is inserted through an opening in the top of the cell container into the electrolyte. Squeezing and releasing the large rubber bulb at the other end of the hydrometer draws electrolyte up into the interior of the hydrometer, causing the glass bulb to float. The depth the bulb submerges depends on the specific gravity of the electrolyte.

In lead acid cells the hydrometer should indicate a reading of 1200 on the stem when the cells are in a charged condition. Evaporated water should be replaced by adding distilled water until the diluted electrolyte just covers the tops of the cell plates. Incorrect electrolyte changes the specific gravity of a cell resulting in loss of power output. Lead acid cells should not be left in a discharged condition as this can greatly shorten the lifespan of the cell.

### 31.3 COMPARISON OF LEAD-ACID AND ALKALINE CELLS

Some of the many factors which have to be considered in comparing secondary batteries are initial cost, life ability to withstand rough usage (both mechanically and electrically) weight, voltage, internal resistance and capacity. In addition any decision as to which type of cell is most suitable will depend upon the nature of the application for which the battery is required.

The alkaline cell possess the following advantages over the lead acid cell.

- (i) It has a longer life.
- (ii) It has a greater mechanical strength.
- (iii) It requires less skilled attention since it is not easily damaged by faulty handling.
- (iv) It can be charged more rapidly.
- (v) Electrolyte does not give off corrosive fumes.
- (vi) It is easy to store and does not deteriorate if left idle or uncharged.
- (vii) For the same capacity and voltage, alkaline batteries have less weight and bulk than lead-acid batteries.

Against the advantages of the alkaline cells, may be set the following disadvantages —

- (i) High initial cost.
- (ii) Its lower voltage necessitates the use of more cells for a given battery voltage.
- (iii) Loss of capacity of nickel-iron cell at low temperatures.
- (iv) High internal resistance as compared to lead-acid cells of the same capacity.
- (v) Large percentage decrease of voltage during discharge.
- (vi) The cell must be discharged at approximately the 5 hour rate to obtain a reasonable efficiency.
- (vii) Efficiency is lower than that of the lead-acid cell.

### 31.4 PERFORMANCE OF SECONDARY CELLS

The efficiency of a cell is determined from the amount of energy that is extracted from the cell, to the amount of energy that is required to be replaced in the cell. The two methods generally used to determine the cell efficiency are -

1. The amp-hour efficiency.
2. The watt-hour efficiency.

The amp-hour efficiency compares the time a current is discharging from a cell or battery to the time taken for a current to recharge the battery to the initial state.

$$\text{Efficiency \%} = \frac{\text{amperes} \times \text{hours (discharge)} \times 100}{\text{amperes} \times \text{hours (charge)}}$$

#### Example 31.1

A cell discharges current to a load at a constant rate of 20 amperes for a period of 5 hours. The cell is then recharged to its initial state at a rate of 10 amperes for a period of 14 hours. Calculate the efficiency percent of the cell.

I (out)	= 20 A				
t (out)	= 5 hours		=	$\frac{\text{amphours (out)}}{\text{amphours (in)}} \times 100$	
I (in)	= 10 A		=	$\frac{20 \times 5 \times 100}{10 \times 14}$	
t (in)	= 14 hours		=	71.4%	
eff. %	= ?				

The watt-hour efficiency uses the ratio of output power over a fixed period to the power and time required to restore the cell or battery to its initial condition.

$$\begin{aligned} \text{Efficiency \%} &= \frac{\text{watts} \times \text{time (out)}}{\text{watts} \times \text{time (in)}} \times \frac{100}{1} \\ &= \frac{E I t \text{ (out)}}{E I t \text{ (in)}} \times \frac{100}{1} \end{aligned}$$

### Example 31.2

A battery maintains a constant potential of 10 volts as it discharges at the rate of 10 amperes for a period of 5 hours. Calculate the efficiency of the cell, if it takes 10 hours to recharge the cell to its initial condition at a fixed voltage of 14 volts and a constant current of 5 amperes.

$$E \text{ (out)} = 10 \text{ V}$$

$$I \text{ (out)} = 10 \text{ A}$$

$$t \text{ (out)} = 5 \text{ hours}$$

$$E \text{ (in)} = 14 \text{ V}$$

$$I \text{ (in)} = 5 \text{ A}$$

$$t \text{ (in)} = 10 \text{ hours}$$

$$\eta = ?$$

$$\eta = \frac{E I t \text{ (out)}}{E I t \text{ (in)}} \times 100$$

$$= \frac{10 \times 10 \times 5 \times 100}{14 \times 5 \times 10}$$

$$= 71.4\%$$

#### Equations in this chapter

$$(1) \text{ Efficiency \%} = \frac{\text{ampere hours (out)}}{\text{ampere hours (in)}} \times \frac{100}{1}$$

$$(2) \text{ Efficiency \%} = \frac{E I t \text{ (out)}}{E I t \text{ (in)}} \times \frac{100}{1}$$

### TUTORIALS 1.31

- (1) A cell that was charged with a current of 20 amperes for 10 hours delivered a current of 40 amperes for 4 hours by which time it has returned to its initial state. Calculate the efficiency of the cell.
- (2) A battery that is 90% efficient delivers a current of 12 amperes over a 6 hour period. Calculate the current necessary to recharge the battery if the recharging process takes 10 hours.
- (3) A battery discharges 28 amperes of current at a constant t.p.d. of 12 volts over a 3 hour period. Calculate the efficiency of the battery if it requires a recharging cycle of 20 amperes at 14 volts for 4 hours to return it to its initial state.
- (4) A battery that is 75% efficient discharges a current of 10 amperes at a constant t.p.d. of 6 volts for 5 hours. Calculate the time required to restore it to its original condition if the charging rate is 5 amperes at a t.p.d. of 8 volts.
- (5) A battery discharges for 4 hours at a constant t.p.d. of 12 volts. It is restored to its original state of charge by recharging it at a constant t.p.d. of 14 volts and a current of 10 amperes for a period of 6 hours. If the battery is 80% efficient, calculate the current when it is discharging.

# TUTORIAL ANSWERS

amperes  
e cell to

1 - 1

- (1)  $R = EI$
- (2)  $R_2 = \frac{R_1 \ell_2}{\ell_1}$
- (3)  $A_1 = \frac{R_2 \ell_1 A_2}{R_1 \ell_2}$
- (4)  $h = \frac{W}{mg}$
- (5)  $E = \sqrt{PR}$
- (6)  $t_c = \frac{\frac{R_h}{R_c} - 1}{a}$
- (7)  $I = \frac{mgh \times 100}{\eta Et}$
- (8)  $t_f = \frac{H}{mC_o C_r} + t_c$
- (9)  $A = \frac{I}{S \mu_o \mu_r}$
- (10)  $N = \sqrt{\frac{L}{\mu A}}$

10

1

1 - 2

- (1)  $r_1 = \frac{1}{\frac{1}{R} - \frac{1}{r_2}}$
- (2)  $I = \sqrt{\frac{P}{R}}$
- (3)  $L = \frac{Z}{2 \pi f}$
- (4)  $E_R = \sqrt{E^2 - (E_c - E_L)^2}$
- (5)  $C = \frac{10^6}{2 \pi f X}$
- (6)  $I = \frac{P}{\sqrt{3} E \cos \phi}$
- (7)  $P = \frac{60 C e}{\Phi Z N}$
- (8)  $E = \frac{\% R V}{100} - V$
- (9)  $R = \sqrt{Z^2 - X^2}$
- (10)  $\Phi = \frac{E}{4.44 f t}$

urrent of 40  
he efficiency

iod.  
akes 10

3 hour  
20 amperes

.p.d. of 6  
ion if the

its  
ent of 10  
rent when

1 - 3

- (a)
- (1) 3.69 kJ
  - (2) 8.46 m
  - (3) 68 m
  - (4) 0.000028 s
  - (5) 63000 g
  - (6) 16 J
  - (7) 11200 W
  - (8) 0.092 km
  - (9) 0.524 kW
  - (10) 0.386431 km
- (b)
- (1) 42 s
  - (2) 40 N
  - (3) 882 kJ
  - (4) 6122 kg
  - (5) 36.75 kW

1 - 4

- (1) 2 A
- (2) 2.4  $\Omega$
- (3) 25 V
- (4) 45 W
- (5) 3.6 kW
- (6) 1.44 kW



1 - 5

- (1)  $\frac{23}{24}$
- (2)  $\frac{27}{28}$
- (3)  $\frac{19}{30}$
- (4)  $\frac{10}{21}$
- (5)  $\frac{13}{100}$
- (6)  $\frac{1}{8}$
- (7)  $\frac{10}{11}$
- (8)  $\frac{7}{24}$
- (9)  $\frac{4.7}{5.0}$
- (10)  $-\frac{1}{6}$

1 - 8

- (1) 5 min
- (2) 1.2 kW
- (3) 196 s
- (4) (a) 2.68 A
- (b) 268000 mV
- (c) 3 k  $\Omega$
- (d) 250000  $\mu$  A
- (e) 200000  $\Omega$
- (f) 0.002864 F
- (g) 0.096 M  $\Omega$
- (h) 2500  $\mu$  A
- (i) 0.01 kV
- (j) 47000 mV

1 - 6

- (1) 2 min
- (2) 80  $\Omega$
- (3) 250  $\Omega$
- (4) 1.26 kW
- (5) 1.25 kW

1 - 7

- (1) 11.4 A
- (2) 1960 kJ
- (3) 9.6  $\Omega$
- (4) 2.45 kW
- (5) 8 kW

1 - 9

- (1) 0.344  $\Omega$
- (2) 200 m
- (3) 66.6 m
- (4) 12 mm<sup>2</sup>
- (5) 0.85  $\Omega$

1 - 10

- (1) 1352.5  $\Omega$
- (2) 32.8°C
- (3) 990000  $\Omega$
- (4) 148°C
- (5) 39.4°C  $\Omega$

1 - 11

- (1) (a)  $13\ \Omega$   
 (b)  $10\ \text{A}$   
 (c)  $20\text{V}, 50\text{V}, 60\text{V}$
- (2) (a)  $440\ \Omega$   
 (b)  $0.5\ \text{A}$   
 (c)  $110\text{V}, 90\text{V}, 20\text{V}$
- (3) (a)  $2.73\ \Omega$   
 (b)  $44\ \text{A}$   
 (c)  $120\ \text{V}$   
 (d)  $8\ \text{A}$
- (4) (a)  $3\ \Omega$   
 (b)  $36\ \text{A}$   
 (c)  $108\ \text{V}$   
 (d)  $18\ \text{A}$
- (5) (a)  $4\ \Omega$   
 (b)  $30\ \text{A}$   
 (c)  $10\ \text{A}$   
 (d)  $120\ \text{V}$

1 - 12

- (1)  $9\ \Omega$
- (2)  $10\ \Omega, 10\ \text{A}$
- (3)  $I = 3\ \text{A}$        $E = 75\ \text{V}$   
 $I_1 = 2\ \text{A}$        $V_1 = 30\ \text{V}$   
 $I_2 = 1\ \text{A}$        $V_2 = 30\ \text{V}$   
 $I_3 = 3\ \text{A}$        $V_3 = 33\ \text{V}$   
 $I_4 = 1\ \text{A}$        $V_4 = 12\ \text{V}$   
 $I_5 = 2\ \text{A}$        $V_5 = 12\ \text{V}$

1 - 13

- (1)  $2.5\ \text{V}$
- (2)  $4\ \text{A}$
- (3)  $I_1 = 7.5\ \text{A} \rightarrow$   
 $I_2 = 5\ \text{A} \swarrow$   
 $I_3 = 4\ \text{A} \nearrow$   
 $I_4 = 7.5\ \text{A} \downarrow$   
 $I_5 = 3.5\ \text{A} \uparrow$   
 $I_6 = 4.5\ \text{A} \swarrow$   
 $I_7 = 4.5\ \text{A} \searrow$   
 $I_8 = 8\ \text{A} \leftarrow$
- (4)  $I_1 = 1.5\ \text{A} \rightarrow$   
 $I_2 = 1\ \text{A} \rightarrow$   
 $I_3 = 1.5\ \text{A} \rightarrow$   
 $I_4 = 2.5\ \text{A} \rightarrow$   
 $I_5 = 0.5\ \text{A} \uparrow$   
 $I_6 = 2\ \text{A} \rightarrow$   
 $I_7 = 1.5\ \text{A} \rightarrow$

1 - 14

- (1) S.S.  $64\%$   
 L.S.  $0.008\%$
- (2) S.S.  $1\%$   
 L.S.  $0.04\%$
- (3) S.S.  $0.1\%$   
 L.S.  $20\%$

1 - 15

- (1)  $26.8\ \Omega$
- (2)  $2.68\ \text{k}\ \Omega$
- (3)  $x = \frac{R}{1000} \%$
- (4)  $160\ \Omega$
- (5)  $244\ \Omega$

1 - 16

- (1) 81.6%
- (2) ~~23.5%~~ *24.3 A*
- (3) 1322 kg
- (4) 5.76 kW
- (5) 55.5 kW

1 - 17

- (1) 46.147 kJ
- (2) 74.18 kg
- (3) 1.16 kg
- (4) 80.1%
- (5) 3.48 kW

1 - 18

- (1) 576 W, 1152 W, 2304 W
- (2) 1002.16 mm
- (3) 289°C
- (4)  $20 \times 10^{-6}$  per unit per °C
- (5) 998 mm

1 - 19

- (1) (a) 40 A  
(b) 125 A  
(c) 250 A
- (2) 290 V
- (3) (a) 1 kW  
(b) 0.1 Ω
- (4) (a) 200 A  
(b) 320 A  
(c) 960 A

1 - 20

- (1) 54.9 Ω
- (2) 4 mm<sup>2</sup>
- (3) (a) 5 Ω  
(b) 24 A
- (4) 87%
- (5) 117°C

1 - 21

- (1)  $0.132 \times 10^6$  At/Wb
- (2) 0.937 N
- (3) 20 T
- (4) 0.002 Wb
- (5) 0.004 N

1 - 22

- (1) 0.156 V
- (2) 3.75 W
- (3) 300 mm
- (4) 2.5 W
- (5) 2.8 V

1 - 23

- (1) 314 mm
- (2) 800 turns
- (3) 209 mH
- (4) (a) 4.25 *mm/s*  
(b) 315 V
- (5) 0.0052 H *25300 H*

1 - 24

- (1) 125.6 Ω
- (2) 0.318 H
- (3) 3.057 A
- (4) 0.1528 H
- (5) 51 Hz

1 - 25

- (1) 1.3275 μF
- (2) 0.02 C
- (3) 400 μF
- (4) 8.2 s
- (5) (a) 117.5 s  
(b) 315 V  
(c) 500 V  
(d) 9 m 48 s

1 - 26

- (1) 0.0016 C  
 (2) 0.025 C  
 (3) (a) 0.001 C  
      (b)  $V_1 = 250 \text{ V}$   
            $V_2 = 166.6 \text{ V}$   
            $V_3 = 83.3 \text{ V}$   
 (4) (a) 0.009 C  
      (b) 0.001 C  
           0.003 C  
           0.005 C  
 (5)  $30 \mu \text{ F}$

1 - 27

- (1)  $212 \Omega$   
 (2)  $63.6 \mu \text{ F}$   
 (3) 5.65 A  
 (4)  $66.3 \mu \text{ F}$   
 (5) 127.3 Hz

1 - 28

- (1) 236 gms  
 (2)  $40\frac{1}{2} \text{ A}$   
 (3) 9 m  $\frac{1}{5} \text{ s}$   
 (4) 2 m 59 s  
 (5) 16.8 A

1 - 29

- (1) 1.25 V  
 (2) 1.44 V  
 (3)  $0.1 \Omega$   
 (4)  $1.8 \Omega$   
 (5) 1.5 V

1 - 30

- (1) 1.8 A  
 (2)  ~~$2.16 \Omega$~~   $21.6$   
 (3) 0.5 A  
 (4)  $1.2 \Omega$   
 (5) ~~6~~ A

1 - 31

- (1) 80%  
 (2) 8 A  
 (3) 90%  
 (4) 10 hrs  
 (5) 14 A